regarding I as a function of c, we have in (15) the equation mathematically expressing the strength of the current maintained by the dynamo when its regular action is reached. Using (15) in (10) we find—

$$r = \frac{E + S}{S} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

which we all knew forty years ago from Joule.

In the shunt-dynamo the whole current, c', of the working coil branches into two streams, c through the electro-magnet, and $c' - c$ through the external circuit, whose strengths are inversely as the resistances of their channels. Still calling the resistance of the external circuit E, we therefore have—

$$c R = (c' - c) E, \text{ which gives } c = \frac{E}{R + E} c' \quad . \quad (18)$$

Hence, by Joule's original law, the expenditures of work per unit of time in the three channels are respectively

$$\left.\begin{array}{lr} R' c'^2 & \text{. . . . working coil} \\ R\left(\frac{E}{R + E}\right)^2 c'^2 & \text{. . electro-magnet} \\ E\left(\frac{R}{R + E}\right)^2 c'^2 & \text{. . external circuit} \end{array}\right\} \quad . \quad (19)$$

Hence, denoting as above by r the ratio of the whole work to the work developed in the external circuit, we have—

$$r = \frac{R' + R\left(\frac{E}{R + E}\right)^2 + E\left(\frac{R}{R + E}\right)^2}{E\left(\frac{R}{R + E}\right)^2} \quad . \quad (20)$$

$$\left.\begin{array}{ll} \text{whence} \quad R^2 r & = R' \frac{(R + E)^2}{E} + R(R + E) \\ & = \frac{R' R^2}{E} + (R + R')E + R(2R' + R) \end{array}\right\} \quad (21)$$

Suppose now R and R' given, and E to be found; to make r a minimum. The solution is—

$$E = \sqrt{\frac{R' R^2}{R + R'}} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and this makes

$$r = 2 \sqrt{\frac{R'(R + R')}{R^2}} + \frac{2R' + R}{R} \quad . \quad . \quad (23)$$

Put now

$$\frac{R'}{R} = e \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

(22) and (23) become

$$E = \sqrt{\frac{R R'}{1 + e}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

$$\text{and} \qquad r = 1 + 2\sqrt{\{e(1 + e)\}} + 2e \quad . \quad . \quad . \quad (26)$$

For good economy r must be but little greater than unity; hence e must be very small, and therefore *approximately*

$$\left.\begin{array}{l} E = \sqrt{(R R')} \\ \text{and} \quad r = 1 + 2\sqrt{e} \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad (25)$$

For example, suppose the resistance of the electro-magnet to be 400 times the resistance of the working coil—that is $e = 400$—and we have, approximately,

$$E = 20R', \text{ and } r = 1 + \tfrac{1}{10}.$$

That is to say, the resistance in the external circuit is twenty times the resistance of the working coil, and the useful work in the external circuit is approximately $\frac{10}{11}$ of that lost in heating the wire in the dynamo.

FUNCTIONAL METAMORPHOSIS OF MUSCLES[1]

THERE is no system in the animal body to which the axiom of Guérin, viz., that "function makes the organ," applies with greater force than to the muscular system. Every student of comparative myology knows that according to the use required of a muscle we have alterations in its volume and connections, or indeed its total disappearance, should its further services in the animal economy be dispensed with. These are the factors which render muscular homologies in many cases so difficult to determine. There is one change, however, which is much more common than is generally believed, viz., the transformation of a muscle into fibrous tissue, or, in other words, its replacement by a ligamentous structure possessing attachments similar to those of its muscular ancestor. It might almost be laid down as a law that whenever a muscle ceases to be of use for contractile purposes, and when, from its attachments, it might be of service as a ligament, that it gradually in course of time becomes transformed into fibrous tissue, and is handed down to posterity in this condition. Indeed should it merely be a case of comparative value, and should the balance of utility be in favour of a ligament, then also will this metamorphosis in all probability take place. Of all adaptations in the muscular system this is perhaps the most beautiful, and instances of it are by no means rare. Thus, in the feet of the armadillo, orycteropus, pig, walrus, and several other animals, certain of the intrinsic pedal muscles have become fibrous bands, indubitably retained for some definite purpose, although their obvious function is often obscure. The most striking examples of this, however, are to be found in the feet of the horse, ox, sheep, camel, and their allies. In these we are able not only to demonstrate with the utmost precision the particular muscles that have become ligamentous, but also the process by which the change has been brought about, and the *rationale* of the transformation.

The *suspensory ligament of the fetlock* in the horse is an exceedingly powerful structure, which lies in the sole of the foot (*i.e.* upon the posterior aspect of the metatarsal bone) under cover of the flexor tendons. It plays an important part in the mechanism of the limb. Its attachments are such that it prevents over extension at the fetlock or metatarso-phalangeal joint, and its value in this respect is evidenced by the fact that when it is ruptured the horse becomes what is termed by veterinary surgeons "broken down." In this condition the fetlock joint sinks downwards towards the ground, whilst the hoof is tilted forwards and upwards.

This ligament is admitted on all hands to be derived from the intrinsic pedal muscles by a transformation of the muscular elements into fibrous tissue; indeed it bears its history written upon its face. Almost invariably a narrow streak of striated muscular fibres can be detected upon its superficial surface which points to its muscular origin. Upon its deep surface fleshy fibres in greater abundance are observed, but these are very pale, owing to a large admixture of fatty tissue.

The question now comes to be—Which of the intrinsic pedal muscles have entered into the formation of this ligament? In making this inquiry we have to keep two points in view: (1) that in the horse the middle or third digit is alone fully developed; and (2) that in a typical pentadactylous foot this digit is supplied by three intrinsic muscles, viz.: a two-headed flexor brevis, and two abductors or dorsal interossei (the second and third) inserted one upon either side of the digit. It is reasonable to conclude, therefore, that the suspensory ligament of the fetlock is derived from one or more of these muscles. But independent remnants of the two dorsal interossei are present, in addition to the ligament, which clearly proves the *flexor brevis medii* to be the source of this structure.

The dorsal interossei in the foot of the horse are of peculiar interest. They are so minute that they can exercise little or no influence upon the movements of the pes. They are simply to be regarded as vestiges of former greatness, and as pointing to retrograde development. They undoubtedly constitute a link in the soft parts between our modern monodactylous horse and its three-toed ancestor. They lead us back to a time when in the foot of this animal there were two distinct interosseous spaces, each filled by a well-marked interosseous muscle.

Still stronger evidence that the suspensory ligament originates solely from the *flexor brevis* of the middle digit is obtained by making thin transverse sections through its substance. We then observe that the sparse remains of muscular tissue are not confined to the surface of the structure, but penetrate into its midst. When the specimen is held against a dark ground, two crescentic opaque outlines are noticed lying side by side in its substance. These undoubtedly represent tracings of the two heads of the flexor brevis, out of which the ligament is developed. On subjecting the outlines to microscopic examination, we find that they are mainly composed of muscular fibres, but every here and there the continuity of this tissue is broken by fatty tissue, in which are observed transversely-divided nerves and blood-vessels.

In the ox, sheep, and camel the suspensory ligament performs the same office as in the horse. The presence, however, of two digits (the middle and annular) complicates somewhat its inferior attachments, in order that it may operate so as to prevent over-extension at both metatarso-phalangeal joints. In each of these animals the structure is undoubtedly formed by the two heads of

[1] Abstract of paper read at the York meeting of the British Association, by D. J. Cunningham, M.D., F.R.S.E., Senior Demonstrator of Anatomy, University of Edinburgh.

two muscles, viz., the *flexor brevis annularis* and the *flexor brevis medii*. Transverse sections of the ligament render this very evident.

In the suspensory ligament of the ox a considerable amount of muscular tissue is found upon both surfaces, and the transverse sections show that this penetrates into its substance in the form of four circular outlines which lie side by side. The fleshy fibres are more abundant than in the case of the horse, but still a considerable amount of fatty tissue enters into the construction of the outlines, and in this are placed nerves and blood-vessels. These four outlines are the remains of the four fleshy bellies of the two flexores breves which amalgamate and transform so as to constitute the ligament.

In the sheep not a trace of muscular tissue is to be found, either on the surface or in the interior of the ligament. The four circular outlines are seen on transverse section, however, but they are entirely formed of fatty tissue. What is of peculiar interest in this case is that in this fat the nerves and blood-vessels are still present.

The camel which the author had an opportunity of examining was a very young specimen, and its foot had been prepared by a fine gelatine and carmine injection. This in some measure obscured the intimate structure of the suspensory ligament. Not a trace of muscular tissue or fatty tissue could be detected either on its surface or in its substance. So complete was its transformation that not a single clue to its origin could be discovered. It is quite possible however that in a fresh uninjected specimen traces might be detected.

The suspensory ligament in these animals has undoubtedly been called into existence by the need for such a structure in the foot, and by the comparatively small value of the intrinsic muscles from which it is developed. The intrinsic muscles of the hand and foot have as their function the production of the more rapid and precise movements of the digits. In the animals which possess a suspensory ligament such a function is of no importance, whereas a powerful brace to provide against over-extension at the metatarso-phalangeal joints is an absolute essential.

But the study of the suspensory ligament of the fetlock suggests other interesting points: 1. The process of transformation of muscle to ligament appears to be effected by a fatty degeneration of the muscular fibres with a coincident multiplication of the connective tissue elements. Here, therefore, is what is usually regarded a pathological change assisting a morphological process. 2. The nerves of supply to the muscles are apparently unaffected by the change. In the sheep, in which there is not a trace of muscular tissue, they are seen in the substance of the ligament of a size relatively as great as in the ox or horse. 3. The presence of muscular tissue, where from its small amount it cannot possibly exercise any appreciable function, is peculiar. To account for its continuous existence we must of course suppose that it remains in a state of tonic contraction. The continuance of nerves in the ligament will enable it to maintain this condition.

SOCIETIES AND ACADEMIES

PARIS

Academy of Sciences, September 12.—M. Wurtz in the chair.—The following papers were read:—Remarks on a memoir of MM. Lœwy and Perigaud on flexure of telescopes, by M. Villarceau.—On the comparative qualities of water of the Isère and of the Durance, as regards irrigation and provision of soil, by M. de Gasparin. He compared the constitution of the liquids at points where all the affluents were united, and at different epochs. The two rivers are closely alike as to the quality of the slime they deposit, that of the Isère being only a little more argillaceous (which slightly favours the state of suspension). Now the Durance is largely utilised for irrigation, and enriches the departments of Bouches-du-Rhône and Vaucluse especially with fertile soil; and it is suggested that a like benefit should be derived from the Isère, in Isère and Drôme.—On a new mode of exploitation of mines of sulphur, by MM. de la Tour du Breuil. They apply the principle of raising the boiling point of water by means of a dissolved salt. Chloride of calcium is so used; the bath containing 66 per cent. of it. The apparatus consists of two rectangular vessels coupled and inclined. When the operation is terminated in one, the boiling liquid is directed into the other, which is previously filled with ore. While liquation is going on (which takes about two hours) the first vessel is emptied and re-charged. One furnace suffices. The sulphur produced is very cheap (about five francs a ton) and pure. Fusion is possible all the year, as no sulphurous acid is produced; and the extraction is very complete.—The Secretary called attention to the subscription opened for a statue to Lakanal at Foix (Ariège).—On radiophony produced by lampblack, by M. Mercadier. Not only is lampblack the best thermophonic agent at present, but it is susceptible, like selenium, of playing the *rôle* of the electric photophone. Instead of selenising one of the faces of his metallic double-spiral receivers, M. Mercadier covers it with lampblack, and they give good effects with intermittent solar, electric-light, and even gas, radiations. When exposed in dark to a copper plate gradually heated with an oxyhydrogen blowpipe, no sound is heard in the telephone till the plate is raised to a dull red; then it gradually increases in intensity. The author is disposed to consider the phenomenon *photophonic* rather than *actinophonic*. The resistance of these receivers diminishes as the temperature rises (from 2° or 3° to 50°), and the variation (very small) is represented nearly by a straight line.—Explanation of a contrast in double circular refraction, by M. Croullebois.—On the magnetic metalls, by M. Gaiffe. He experimented with nickel and cobalt, obtained electro-chemically and variously treated before magnetising; some bars being kept hard, others annealed, and others annealed and forged. The figures show what a comparatively great coercitive force these metals (and especially cobalt), may acquire in a pure state, while pure iron, obtained by the same means, gives inappreciable deflections in the magnetometer. The annealed and forged samples produced the greatest effects (the annealed coming next). The weak coercitive force of the metals on issuing from the galvanoplastic bath, is attributed to the presence of hydrogen in combination with them.—On metaldehyde, by MM. Henriot and Oeconomoides.—On the rotatory power of albuminoid substances of blood-serum, and their determination by circumpolarisation, by M. Fredericq.—On permanganate of potash employed as antidote to the poison of serpents, by M. de Lacerda. A solution of snake poison having been injected subcutaneously under the thigh of a dog, and a 1 per cent. solution of permanganate of potash a few minutes after, the latter prevented all local lesion (abscess, &c.); there was merely a very slight swelling. In other cases of injection into the veins the permanganate proved a powerful antidote.—M. Maumené communicated accounts of a new apparatus for fractional distillation, and of one for measuring the alcoholic richness of mixtures of alcohol and water.

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